UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 10
1200 Sixth Avenue
Seattle, WA 98101

Reply To
Attn Of: ECL-115

April 19, 2006

James M. Anderson
DEQ Northwest Region
Portland Harbor Section
2020 SW Fourth Ave, Suite 400
Portland, OR 97201

RE: Storm Water Discharge Characterization

Dear Mr. Anderson:

I am writing you this letter because EPA has a shared interest in DEQ's identification and control of upland sources to the Portland Harbor Superfund Site in the lower Willamette River. As lead for the in-water response work, EPA is concerned about contaminants in storm water that have the potential to recontaminate the Site after remedies (e.g., dredging and capping) have been implemented. EPA believes that it is important to characterize what contaminants are being released to the Superfund Site in storm water, and identify facilities that are sources of those contaminants. Since early actions are underway and remedies may be initiated as early as 2009, it is critical to begin storm water characterization soon to allow DEQ time to work with facility owners or operators in controlling storm water that may have the potential to recontaminate the river. From our experience at other Superfund sediment sites, the following information should be provided to you by facility owners or operators of potential upland sources:

- **Historical Site Activities.** Historical information about site operations (e.g., manufacturing, or other industrial processes, transportation-related activities, equipment of vehicle maintenance or washing, outdoor storage, on-site waste disposal, dust or particulate generating activities), including a list of possible chemicals used or stored at the site;
- **Current Site Activities.** A list of current site operations within drainage areas, including a list of possible chemicals used or stored at the site;
- **Map of Storm Water System.** A map of site drainage areas, pervious (e.g., gravel or lawn) and impervious areas (e.g., paved areas), catch basins, conveyance lines, access points (e.g., manholes), and discharge points (indicate NPDES permitted storm water discharges);

- **Video of Storm Water System.** Any video of storm water lines;
- **Storm Water Monitoring.** Sample results of Portland Harbor contaminants of interest in the storm water conveyance system, including storm water (whole water and solids) collected during local "wet weather" period;
- **Storm Water Control Measures.** A description of any source control measures (e.g., conveyance line or catch basin cleaning) already taken at your property and the results of those measures (e.g., reduction in release of a contaminant with before and after monitoring results);

We have enclosed a summary of storm water characterization activities we believe are necessary in evaluating storm water discharges; this is not meant to supersede the *Portland Harbor Joint Source Control Strategy, Final* (December 2005).

Additionally, EPA believes that it may be advantageous to hold a joint storm water monitoring workshop in June/July of this year to allow storm water dischargers to ask specific questions about characterizing their storm water conveyance system. We would like to hear your thoughts regarding this workshop.

Should you have any questions or concerns regarding this letter, please contact me at (206)553-6705 or koch.kristine@epa.gov.

Sincerely,

Kristine M. Koch
Source Control Project Manager
Portland Harbor
USEPA, Region 10

encl.

ENCLOSURE 1
Summary of Storm Water Characterization Activities

Step 1. Knowledge of Site Storm Water Conveyance System

Knowledge of the site storm water system must be fully understood before conducting any storm water monitoring. There may be more to storm water than just rain; there are other source potentials than just the water running into the drain. When learning the site's storm water collection system, consideration should be made for upstream sources (e.g., sheet flow from an adjacent facility, contaminants from site activities, etc.), infiltration and inflow (I/I) (i.e., contaminated groundwater commingling with site storm water discharge), and the backfill around the storm water lines (i.e., preferential pathway for contaminated groundwater) as possible contributors to the discharge.

First, a facility should know their storm collection system structure by reviewing any as-built drawings, and construction and maintenance history. Not all storm water collection systems have complete drawings or any drawings at all due to when the system was constructed (e.g., various parts of the system were not constructed at the same time). It may be necessary to use other means (e.g., field testing) to determine the system structure. This is important to know where to sample and identify any hazardous conditions (e.g., chemical exposure, biological hazards [rodents, snakes, insects, etc.], physical surroundings [traffic, sharp edges, falling object, slippery footing, etc.], confined spaces, etc.).

Second, a facility should verify the drainage area and where the water runs to when it rains. This information will help in knowing the sources contributing to a storm water outfall and in calculating the volume of storm water discharged through the outfall.

Third, a facility should check the integrity of the storm system for I/I, dislocated or collapsed lines and structures, overflowing or bypass structures, staining and odor, low points within the collection system. These can be potential sources from groundwater, point sources, or other storm water.

Lastly, a facility should know historical activities and which drainage basins they were located in because facilities with a long history of storm water discharge will likely have historical contamination in the lines of the storm water structures. Getting to know the site's storm water system can help clear out historic accumulations and enable better efficiency in controlling current discharges.

Step 2. Develop A Monitoring Plan

A facility should plan the storm water monitoring activities prior to conducting them by developing a monitoring plan. A monitoring plan includes: the media (i.e., water, solids, etc.) to be monitored; the contaminants of interest; monitoring location(s); timing of monitoring (i.e., when to take the samples); sample type (e.g., grab, automatic time-weighted composite, manual time- weighted grab-composite), sampling protocols (e.g., how to collect sample, sample handling and preservation, decontamination of equipment and containers, sample preservation and holding times, sample volumes, sample labeling, sample custody procedures, sample packaging and shipping, etc.); appropriate analytical methods; and recordkeeping. These are all discussed in the following substeps:

Step 2a. Sampling Media

Storm water monitoring should be conducted on both phases (whole water and solids) during a local "wet weather" period. The purpose of sampling both the whole water (water and dissolved solids) and the solids (suspended solids, sand and silt, gravel, etc.) for recontamination potential for the River sediments is to determine the total mass loading (concentration * flow) to the River. Contaminants in the water phase can flocculate in the River environment and settle onto the River sediment, contaminants is suspended solids in the water phase can either settle in quiescent zones in the River or flocculate in the River environment and settle onto the River sediment, and solids will settle onto the River sediment. Sampling during local "wet weather" periods is discussed in Step 2d, below.

Step 2b. Contaminants of Interest

The Portland Harbor contaminants of interest include metals (e.g., arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc), semivolatile organic compounds (SVOCs), phthalates, chlorinated pesticides (e.g., DDT, DDE and DDD), chlorinated herbicides, polychlorinated dibenzo-p-dioxins and furans (PCDDs and PCDFs), total petroleum hydrocarbons (TPH), polynuclear aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs). At a minimum, a facility should monitor their storm water for these contaminants, as well as grain size (if there is enough sample) and organic carbon in the solid phase, unless DEQ authorizes a revised list of contaminants for a given source site.

Step 2c. Selecting Monitoring Location

Many facilities will have multiple storm water drains from their property. All storm water drains must be characterized to determine if source control measures are necessary. The monitoring point(s) must represent the storm water from a facility; therefore, they should be located as close to the end-of-pipe but prior to mixing with other sources (e.g., prior to commingling with storm water from other sources), to the extent practicable. Additionally, sampling location(s) must be easily and safely accessible.

If more than one drainage area has similar activities and site conditions, and there is reason to believe pollutant types will be similar, a single sampling point can be used to represent these drainage areas, although the facility must choose the discharge with the highest loading potential (i.e., the discharge with the largest mass flux [= concentration * flow]). Determination of this sampling point can be approached as a logical deduction or using sampling results from these discharges. Documentation and justification of the sample site selection must be provided in the Storm Water Characterization Report (refer to Step 7, below).

Since there are a many different types of collection systems throughout the Site, there is no single place that can be prescribed as "acceptable" by the DEQ for characterization of storm water. Therefore, it is important for a facility to know their system and discuss where and how they plan to collect samples with the DEQ prior to commencing sampling activities. This will ensure that the samples are representative of the discharge.

Step 2d. Timing of Monitoring

Monitoring storm water depends on the media (i.e, whole water or solids). Whole water monitoring should be conducted on a storm event basis (i.e., from time rainfall begins to time rainfall ends), while solids monitoring should be based upon a storm season (e.g., October through May).

Whole water, which is an unfiltered sample of the water portion of the discharge, should be collected from at least four (4) storm events to allow for full characterization of the discharge and its variability. Whole water monitoring should be conducted after a period of dry weather (i.e., at least 24-hours where there is less than "trace" or 0.02" rainfall) and during a local wet weather period. A local "wet weather" period is defined as a storm with a rainfall intensity of at least 0.25 inches in a 24-hour period. This does not mean that the rainfall must last for a full 24 hours, only that from the time it begins raining to the time you stopped sampling the rainfall is of the recommended intensity. To determine this, a facility should observe the record the time it began raining as well as the time you stopped sampling: a simple, inexpensive rain gauge and a watch will give you this information (i.e., water level in rain gauge and time when sampling began and stopped). The change in water level divided by the change in time during the sampling event, with correction for units, must be greater than the rainfall intensity for a wet weather period.

Example of calculating rain intensity:

Rainfall begins at 9:35 AM and the rain gauge reads 0 inches of rain. You complete sampling at 10:30 and your rain gauge reads 0.01 inches of rain.

$$\text{Rain intensity} = \frac{\Delta \text{ inches rain}}{\Delta \text{ time}} = \frac{0.01 \text{ inches}}{55 \text{ minutes}} \times \frac{60 \text{ minutes}}{\text{hour}} \times \frac{24 \text{ hours}}{24\text{-hours}} = \frac{0.26 \text{ inches}}{24\text{-hours}}$$

Since the criterion for rain intensity is greater than 0.25 inches per 24 hour period, the rain intensity for the sampling event of 0.26 inches per 24 hours meets the recommended criterion.

Success in collecting whole water samples requires keeping up with the weather forecast and planning so that sampling can be carried out on short notice. Local forecasts, including televised satellite and radar images can give an indication of the expected intensity of coming storms. The National Weather Service is an excellent source of information on upcoming storms. Their website, which includes local current radar and satellite images, is found at http://www.wrh.noaa.gov/seattle. There are also a number of commercial websites that provide weather information and forecasts, such as http://www.weather.com and *Yahoo*.

Solids monitoring should be collected during at least one storm season to allow full characterization of the loading potential of solids to the Site. If in-line structures (e.g., sumps, catch basins) are used to collect the solids portion of the storm water, a facility should clean out the structure prior to the beginning of the storm season.

Step 2e. Sample Type

For any given storm, storm water contaminant concentrations are likely to change over time (i.e., concentrations can change throughout the storm event). Likewise, runoff from one storm to the next is also not constant. Thus, representative storm water samples for a given storm must be collected as composite samples and representative storm water loading potential to the Superfund Site should consist of monitoring multiple storms over a wet season. It is not appropriate to collect a grab sample since it only represents the time, place, and composition at the time it was collected and will not provide adequate characterization of the storm water discharge or loading potential.

Whole water samples can be collected using an automatic sampler or manually as grab-composites (i.e., a series of grab samples manually collected at regular intervals during the storm event that are mixed and analyzed as one sample) to accurately characterize the storm event. Sampling does not need to occur throughout the entire storm event, but should commence at the beginning of the storm event and continue until the storm event plateaus.

Solids samples that are collected throughout a storm season in one collection device are composite samples of the entire time solids are collected in it. Therefore, a grab sample from a well mixed solids composite sample will represent the storm water solids. Sometimes it is necessary to remove the sample collection device because it becomes full during the storm season. In this instance, the facility should remove the sampling device, empty the contents, and replace the sampling device to continue capturing storm water solids during the storm season. The contents should be analyzed and reported as representing the duration of time (e.g., 3 months). It is not appropriate to average the results of multiple solids samples since they may represent different volumes of storm water; however, if the facility knows or can estimate the volume of storm water associated with the sample, they can do a weighted average at the end of the storm season.

Step 2d. Sampling Protocols

It is important to know how samples are going to be collected and the supplies that will be needed before you start monitoring storm water. Some things to consider prior to sampling include: how to collect sample, sample handling and preservation, decontamination of equipment and containers, sample preservation and holding times, sample volumes, sample labeling, sample custody procedures, and sample packaging and shipping. To ensure that the samples are representative of the discharge, it is important for a facility to know their storm water collection system and discuss how they plan to collect samples with the DEQ prior to commencing sampling activities.

Step 2e. Analytical Methods

Samples must be analyzed using appropriate EPA analytical methods for the media (i.e., water or solids) that quantitate the discharge concentrations of the contaminants of concern (i.e., practical quantitation limits need to be below the SLVs in Table 3.1 of the Portland Harbor Joint Source Control Strategy). Whole water should be filtered in the laboratory and both the water and the filtrate should be analyzed for contaminants of interest.

<u>Step 2f. Recordkeeping</u>

Field log books should be kept to help in recording field information necessary for storm water characterization reports. Information for each storm sampled should be recorded in the field log books. The recorded information should include the sampling date, time rainfall began, start and end time of sampling, volume of each sample collected, sample location, sample collection method, name of sampler(s), number of samples, field measurements, and any unusual circumstances that may affect sample results.

<u>Step 3. Clean Out Storm Conveyance System and Sample Solids</u>

Prior to commencing storm water sampling, it may be necessary to clean out solids that have accumulated historically in the storm conveyance. This is especially important for facilities that have had multiple owners or operators with varying site activities and where there is no maintenance or cleaning records for the storm conveyance system. It is also important because the current owner or operator wants to characterize only their current storm water discharge. However, any solids removed from the storm conveyance system should be sampled and analyzed to discern historical discharges from current discharges from this facility. The analytical results of historical storm water solids should be presented in the storm water characterization report.

<u>Step 4. Conduct In-line Storm Water Solids Sampling</u>

Solids sampling should be conducted in accordance with your storm water monitoring plan. Solids monitoring should be collected during at least one storm season (e.g., October through May) to allow full characterization of the loading potential of solids to the Willamette River. In order to capture solids for the entire storm season, the in-line solids collection devise should be installed at the beginning of the storm season, if necessary. Any installed devise should be checked periodically to ensure the integrity of the devise (e.g., has it been displaced, is the collection devise full, has it been damaged).

If in-line structures (e.g., sumps, catch basins) are used to collect the solids portion of the storm water, they should be cleaned out prior to the beginning of the storm season. The in-line structure should be checked periodically to ensure the collection devise has not filled up.

Sometimes it is necessary to clean out the sample collection device because it becomes full during the storm season. In this instance, the facility should remove the sampling device (if necessary), take out the contents, and replace the sampling device (if necessary) to continue capturing storm water solids during the storm season. The contents should be analyzed and reported as representing the duration of time (e.g., October 1 through December 12).

<u>Step 5. Conduct Whole Water Sampling</u>

Whole water sampling should be conducted in accordance with the facility's storm water monitoring plan. Whole water samples are collected at regular intervals during the storm event and mixed and analyzed as one sample to accurately characterize the storm event. Sampling does not need to occur throughout the entire storm event, but should commence at the beginning of the storm event and continue until the storm event plateaus. Therefore, success in collecting whole water samples requires keeping up with the weather forecast and planning so that sampling can be carried out on short notice. Local forecasts, including televised satellite and radar images can give an indication of the expected intensity of coming storms. The National Weather Service is an excellent source of information on upcoming storms. Their website, which includes local current radar and satellite images, is found at http://www.wrh.noaa.gov/seattle. There are also a number of commercial websites that provide weather information and forecasts, such as http://www.weather.com and *Yahoo*.

Step 6. Compare Monitoring Results to Screening Level Values

Once a facility receives the analytical results of their storm water, the concentrations should be compared to the Screening Level Values (SLVs) in Table 3.1 of the Portland Harbor Joint Source Control Strategy. This table can be found at http://www.deq.state.or.us/nwr/PortlandHarbor/JSCS.htm. Those contaminants that exceed the SLVs should be identified in the storm water characterization report.

Step 7. Prepare and Submit Storm Water Characterization Report

A storm water characterization report should be sent to the DEQ to determine if source control measures are necessary at the facility. The Report should include historical and current activities (e.g., manufacturing, or other industrial processes, transportation-related activities, equipment of vehicle maintenance or washing, outdoor storage, on-site waste disposal, dust or particulate generating activities), a list of all chemicals historically and currently used at the site, a map of the storm water conveyance system including drainage basins, any video of the storm water conveyance system, hydrographs of storm events (or duration of storm event and total inches rainfall), field sampling records (sampling date, time rainfall began, start and end time of sampling, volume of each sample collected, sample location, sample collection method, name of sampler(s), number of samples, field measurements, unusual circumstances that may affect sample results), number of dry days before the day the sample was collected, rainfall intensity, analytical results, mass (concentration x volume discharged) and concentration discharged during storm events, and a list of contaminants that exceed the SLVs. (An example of how to determine the volume discharged is provided in enclosure 2.) Additionally, any source control measures taken at the site and the results of those measures should be included in the report.

Step 8. Implement Source Control Measures

The DEQ will determine if source control measures at the site are necessary based on the information provided in the storm water characterization report. The DEQ will use the process provided in the Portland Harbor Joint Source Control Strategy to determine whether or not the site needs to implement storm water source control. An exceedance of an SLV will not necessarily mean that source control measures are necessary, although a facility may want to investigate the sources of these contaminants and control or eliminate them.

Source control measures may include: best management practices (BMPs) to prevent contaminants from entering the storm conveyance system; removal or capping of contaminated surface soils that may be entering the storm conveyance system; upgrades and maintenance of the storm conveyance system to prevent I/I (e.g., contaminated groundwater) from entering the system; installation of treatment systems (e.g., oil-water separators). Typical storm water BMPs include, but are not limited to, the following: frequent sweepings to reduce the release of suspended solids; installation of drip pans or berms; regular cleaning of catch basins and conveyance line flushing; placement of erosion control devices around catch basins; and installation of secondary containment systems around hazardous material storage or other waste management areas.

Step 9. Evaluate Source Control Measures

After source control measures have been implemented, steps 4, 5, and 6 should be repeated to ensure that the source control measures have been effective in reducing or eliminating contaminants of concern from the storm water discharge. Further source control measures may be necessary if the release of contaminants from the facility has the potential to recontaminate the Portland Harbor Superfund site after remedies are implemented.

Step 10. Prepare and Submit Source Control Document to the DEQ

When a facility has conducted source control measures at their site, either in conjunction with the DEQ or on their own, the facility should submit a source control document to the DEQ that identifies the source control measures taken at the site and the effectiveness of those source control measures.

ENCLOSURE 2
Example for Determining Total Volume Discharged

Since accurate measurement of total volume discharged is often impracticable due to lack of equipment, total volumes are more commonly estimated. The total volume discharged can be determined from either rainfall or measured data. The following presents two methods that require only simple estimated measurements. The first method is based on rainfall depths and runoff coefficients and the send is based on flow rates that can either be measured or estimated.

Method 1. Total Volume from Rainfall Data

Discharge volumes are most easily estimated using the area of the drainage basin contributing to the outfall, the rainfall accumulation, and a runoff coefficient. The total volume of discharge can be estimated using a simple equation that relates the amount of rainfall to the volume of discharge that will leave the site as runoff. The equation is as follows:

$$V_t = R_f \text{ x } [(A_{paved} \text{ x } C_{runoff}) + (A_{unpaved} \text{ x } C_{runoff})]$$

where: V_t = the total runoff volume in cubic feet
R_f = the total rainfall measured in feet
A_{paved} = the area in square feet within the drainage basin that is paved or roofed
$A_{unpaved}$ = the area in square feet within the drainage basin that is unpaved
C_{runoff} = a specific runoff coefficient (unitless) for the drainage area ground cover

Runoff coefficients represent the fraction of total rainfall that will be transmitted as runoff from the drainage area that flows into the facility outfall. Runoff coeffients consider the ground surface or cover material and determine the amount of storm water flow which may infiltrate or runoff as a discharge. A simple estimate of runoff volume assumes that paved areas and other impervious structures (e.g., roofs) have a runoff coefficient of 0.90 (i.e., 90 percent of the rainfall leaves the area as runoff) and unpaved surfaces have a runoff coefficient of 0.50. A more accurate estimate can be made by using more specific runoff coefficients for different areas of the facility based on the specific type of ground cover. Typical runoff coefficients are provided in Table 1.

Table 1. Typical Runoff Coefficients for 5- to 10-year Frequency Design Storms	
Description of Area	**Runoff Coefficients**
Business	
Downtown areas	0.70 – 0.95
Neighborhood areas	0.50 – 0.70
Residential	
Single-family areas	0.30 – 0.50
Multiunits (detached)	0.40 – 0.60
Multiunits (attached)	0.60 – 0.75
Residential (suburban)	0.25 – 0.40
Apartment dwelling area	0.50 – 0.70
Industrial	
Light areas	0.50 – 0.80
Heavy areas	0.60 – 0.90
Parks and cemeteries	0.10 – 0.25
Playgrounds	0.20 – 0.35
Railroad yard areas	0.20 – 0.40
Unimproved areas	0.10 – 0.30
Streets	
Asphalt	0.70 – 0.95
Concrete	0.80 – 0.95
Brick	0.70 – 0.85
Drives and walks	0.75 – 0.85
Roofs	0.75 – 0.95
Lawns – course textured soil (greater than 85% sand)	
Slope: Flat (2 percent)	0.05 – 0.10
Average (2-7 percent)	0.10 – 0.15
Steep (7 percent)	0.15 – 0.20
Lawns – fine textured soil (greater than 40% clay)	
Slope: Flat (2 percent)	0.13 – 0.17
Average (2-7 percent)	0.18 – 0.22
Steep (7 percent)	0.25 – 0.35

Source: *Design and Construction of Sanitary Storm Sewers*, American Society of Civil Engineers, *Manual of Practice*, page 37, New York, 1960.

This method involves the following steps:

Step 1: Determine the area of drainage contributing to the runoff volume at the outfall and convert it to square feet.

Step 2: Determine the total Rainfall depth during the event that was sampled to the nearest one-hundredth of an inch and convert it to feet.

Step 3: Determine the runoff coeffients for each area.

Step 4: Calculate the volume of flow using the following formula and convert the volume to liters.

<u>Example</u>:

Step 1: Using a land survey, a facility has determined its site encompasses 0.3 acres (13,068 square feet). The entire site is used for industrial activities, and therefore, any storm water discharges from the site will be associated with industrial activity. A berm surrounds the entire site limiting the drainage area to the site itself and preventing any dilution or contamination from other discharges.

Step 2: From the rain gauge, the rainfall accumulation is measured at 0.6 inches (0.05 feet).

Step 3: The facility has estimated that 1/3 of the site (4,356 square feet) is covered by impervious surfaces and 2/3 of the site (8,712 square feet) is unpaved.

Step 4: V_t = 0.05 x [(4,356 x 0.90) + (8,712 x 0.50)
Total Volume = 413.8 cubic feet (11,720 liters)

Method 2. <u>Total Volume from Flow Rate Data</u>

The total volume can also be estimated using a series of measured or estimated flow rates. In this method, the total volume is estimated by first multiplying each of the flow rates by the time interval in between flow measurements. This time period represents the portion of the total storm duration that can be associated with the flow rate measurement. Adding all such partial volumes results in a total volume of storm water discharged.

Method 2a. Total Volume from Measured Flow Rate Data

The procedure for calculating the total runoff volume from a set of discrete measurements of flow depth and velocity in a ditch during a storm runoff event is presented in the following steps:

Step 1: When each sample or aliquot is taken, record the data for the time the sample was taken in column B of Table 1a.

Step 2: Using a flow meter, measure the flow velocity (in feet per minute) when each sample aliquot is taken and record the data in column C of Table 1a.

Step 3: Using a measuring stick, measure the flow depth (in feet) when each sample aliquot is taken and record the data in column D of Table 1a.

Step 4: Measure the width of the ditch where the samples are collected and record the data in column E of Table 1a.

Step 5: Calculate the flow rate by multiplying the values in columns C, D, and E and record the results in Column F of Table 1a.

Step 6: Plot the flow rate versus time (column F vs. column B). Assume that the flow rate is zero at the beginning (time = 0) and end of the sampling event (i.e., assume that flow drops uniformly from the last calculated flow rate to zero at the time when the next sample would have been taken.).

Step 7: Calculate the total flow volume (V_t) by geometrically determining the area under the curve. The summation of the individual volumes per increment of time is the total flow volume of the event.

TABLE 1a

A	B	C	D	E	F
Sample Number	**Time (minutes)**	**Flow Velocity (feet per minute)**	**Flow Depth (feet)**	**Ditch Width (feet)**	**Calculated Flow Rate (cfm)**

Example:

Steps 1, 2, and 3: Flow velocity and flow depth are measured and recorded in Table 1a every 20 minutes for a period of 3 hours while samples of storm water are collected.

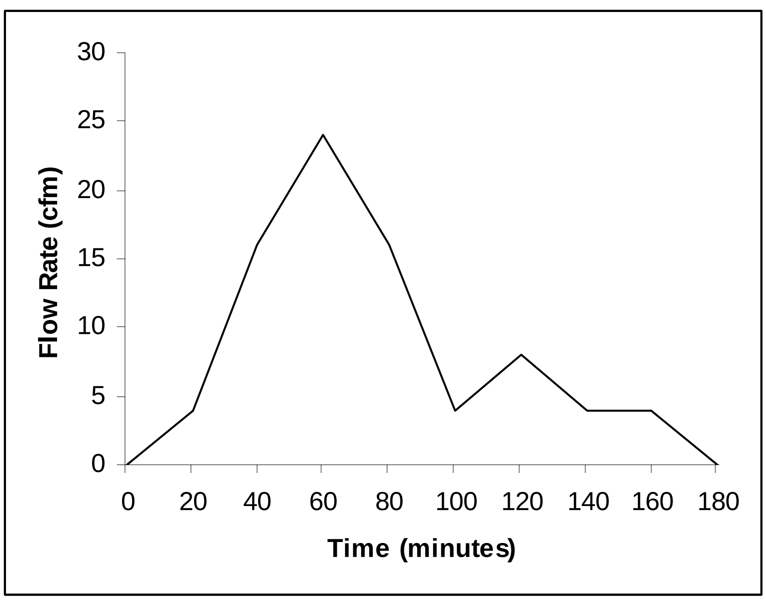
Step 4: The width of the ditch where the samples are collected is 5 feet.

Step 5: Calculate the flow rate in cubic feet per minute by multiplying columns C, D, and E for each sample. For example, the calculated flow rate for sample 2 is calculated as:

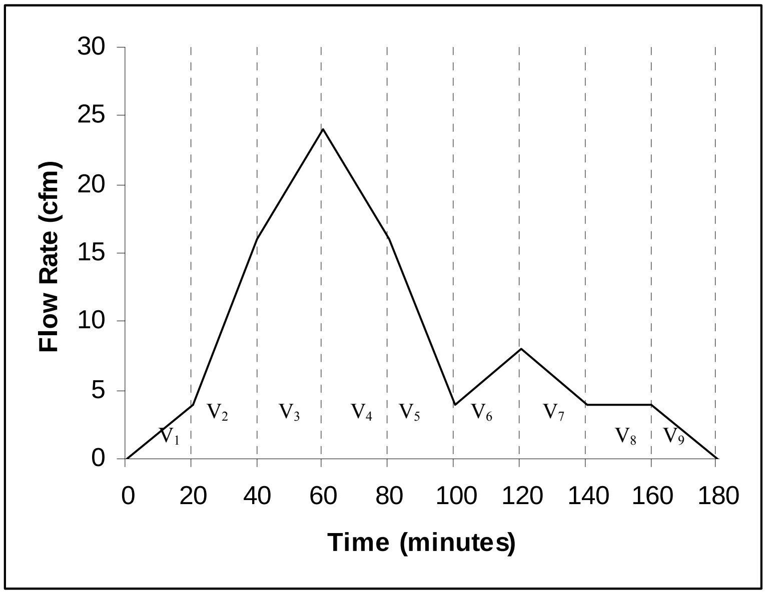
Flow Rate (cfm) = flow velocity (ft/min) x flow depth (ft) x ditch width (ft)
= 4 x 0.2 x 5
= 4 cfm

TABLE 1a					
A	**B**	**C**	**D**	**E**	**F**
Sample Number	**Time (minutes)**	**Flow Velocity (feet per minute)**	**Flow Depth (feet)**	**Ditch Width (feet)**	**Calculated Flow Rate (cfm)**
1	0	-	-	5	-
2	20	4	0.2	5	4
3	40	8	0.4	5	16
4	60	12	0.4	5	24
5	80	8	0.4	5	16
6	100	4	0.2	5	4
7	120	8	0.2	5	8
8	140	4	0.2	5	4
9	160	4	0.2	5	4

Step 6: Plot the flow rate versus time (column F vs. column B). Assume that the flow rate is zero at the beginning (time = 0) and end of the sampling event (i.e., assume that flow drops uniformly from the last calculated flow rate to zero at the time when the next sample would have been taken.).



Step 7: Calculate the total volume geometrically by determining the area under the curve.



$V_1 = V_{\text{Time 0 to Time 20}} = ½ (Q_2 – Q_1)(t_2 – t_1) = ½ (4 – 0)(20 – 0) = 40\ ft^3$
$V_2 = ½ (Q_2 – Q_3)(t_3 – t_2) + Q_3 (t_3 – t_2) = ½ (16 – 4)(40 – 20) + 4 (40 – 20) = 200\ ft^3$
$V_3 = ½ (Q_4 – Q_3)(t_4 – t_3) + Q_3 (t_4 – t_3) = ½ (24 – 16)(60 – 40) + 16 (60 – 40) = 400\ ft^3$
$V_4 = V_3 = 400\ ft^3$
$V_5 = V_2 = 200\ ft^3$
$V_6 = ½ (Q_6 – Q_7)(t_7 – t_6) + Q_7 (t_7 – t_6) = ½ (8 – 4)(120 – 100) + 4 (120 – 100) = 120\ ft^3$
$V_7 = V_6 = 120\ ft^3$
$V_8 = Q_9 (t_9 – t_8) = 4 (160 – 140) = 80\ ft^3$
$V_9 = V_1 = 40\ ft^3$

$V_t = V_1 + V_2 + V_3 + V_4 + V_5 + V_6 + V_7 + V_8 + V_9 = 1{,}600\ ft^3$
Total Volume = 1,600 cubic feet (45,300 liters)

Method 2b. <u>Total Volume from Estimated Flow Rate Data</u>

The procedure for calculating the total runoff volume from estimating flow during a storm runoff event using a set of discrete measurements of rainfall depth during a storm runoff event is presented in the following steps:

Step 1: Estimate the runoff coeffients for the drainage area that contributes flows to the sampled outfall using the following equation:

$$\text{Outfall Runoff Coefficient} = \frac{(\text{Area A})(\text{Coefficient A}) + (\text{Area B})(\text{Coefficient B}) + \ldots}{\text{Area A} + \text{Area B} + \ldots}$$

where: Area A = area of drainage basin A
Area B = area of drainage basin B

Coefficient A = runoff coefficient for drainage basin A
Coefficient B = runoff coefficient for drainage basin B

The area of the drainage basin can generally be obtained from land surveys conducted at the time of facility purchase or site surveys taken from design documents developed as part of construction planning. If these are not available, then the drainage areas may be estimated from a topographical map of the areas.

Step 2: When each sample or aliquot is taken, record the data for the time the sample was taken in column B of Table 1b.

Step 3: Using a rainfall gauge, measure the total rainfall depth (in inches) when each sample aliquot is taken and record the data in column C of Table 1b.

Step 4: Calculate the incremental time since the last flow measurement and record the data in column D of Table 1b.

$$\text{Incremental Time} = \text{Time}_{\text{current sample}} - \text{Time}_{\text{previous sample}}$$

Step 5: Calculate the additional or incremental rainfall that has occurred since the last measurement using the following equation and record the results in column E of Table 1b.

$$\text{Incremental Rainfall} = \text{Total Rainfall}_{\text{current sample}} - \text{Total Rainfall}_{\text{previous sample}}$$

Step 6: Calculate the flow rate using the following equation and record the results in column F of Table 1b (watch units).

$$\text{Flow Rate (cfm)} = \frac{\text{(drainage area)(runoff coefficient)(incremental rainfall)}}{\text{(incremental time)}}$$

TABLE 1b					
A	**B**	**C**	**D**	**E**	**F**
Sample Number	**Time (minutes)**	**Total Rainfall Depth (inches)**	**Incremental Time (minutes)**	**Incremental Rainfall (inches)**	**Calculated Flow Rate (cfm)**

Step 7: Plot the flow rate versus time (column F vs. column B). Assume that the flow rate is zero at the beginning (time = 0) and end of the sampling event (i.e., assume that flow drops uniformly from the last calculated flow rate to zero at the time when the next sample would have been taken.).

Step 8: Calculate the total flow volume (V_t) by geometrically determining the area under the curve. The summation of the individual volumes per increment of time is the total flow volume of the event.

<u>Example</u>:

Step 1: Assume the drainage area to outfall A is 3 acres. Two of those acres are paved with a runoff coefficient of 0.9, and one acre is unpaved with a runoff coefficient of 0.5.

$$\text{Outfall Runoff Coefficient} = \frac{(2)(0.9) + (1)(0.5)}{2 + 1} = 0.77$$

Steps 2 and 3: Rainfall is measured from a rain gauge and recorded in Table 1b every 20 minutes for a period of 3 hours while samples of storm water are collected.

Step 4: Calculate the incremental time for each sample in Table 1b using the values in column B and record in column D. The incremental time will always be zero for sample 1. For example, the incremental time for sample 2 is calculated as:

$$\begin{aligned}\text{Incremental Time} &= \text{Time}_{\text{current sample}} - \text{Time}_{\text{previous sample}} \\ &= 20 - 0 \\ &= 20\end{aligned}$$

Step 5: Calculate the incremental rainfall for each sample in Table 1b using the values in column C and record in column E. The incremental rainfall will always be zero for sample 1. For example, the incremental rainfall for sample 3 is calculated as:

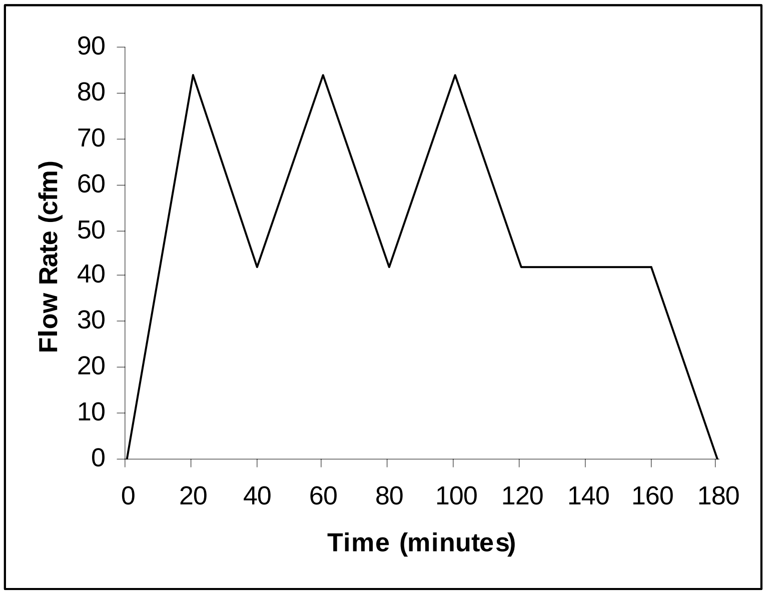
$$\begin{aligned}\text{Incremental Rainfall} &= \text{Total Rainfall}_{\text{current sample}} - \text{Total Rainfall}_{\text{previous sample}} \\ &= 0.3 - 0.2 \\ &= 0.1\end{aligned}$$

Step 6: Calculate the flow rate for each sample in Table 1b using the information in Step 1 and the values in columns D and E. For example, the calculated flow rate for sample 2 is calculated as:

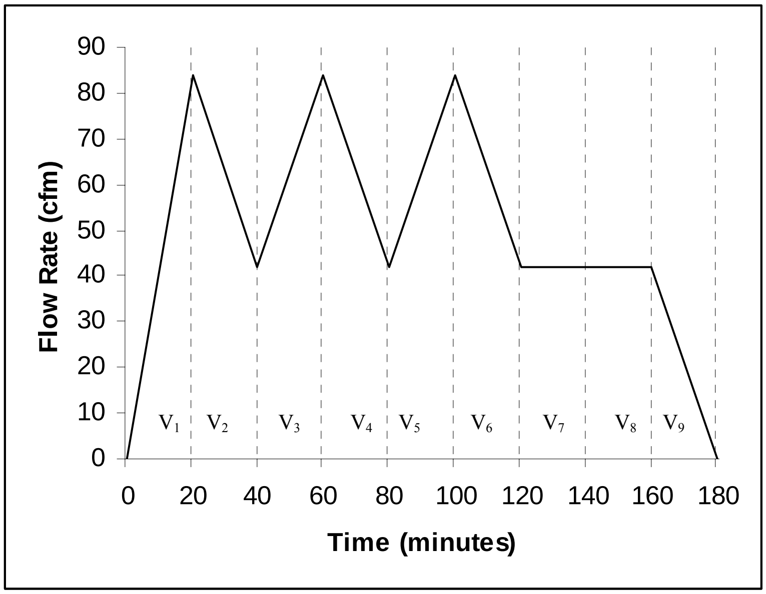
$$\begin{aligned}\text{Flow Rate (cfm)} &= \frac{\text{(drainage area)(runoff coefficient)(incremental rainfall)}}{\text{(incremental time)}} \\ &= \frac{\text{(3 acres)(0.77)(0.2 inches)}}{\text{(20 minutes)}}\,(43{,}560\ \text{ft}^2/\text{acre})(1\ \text{ft}/12\ \text{in}) \\ &= 84\ \text{cfm}\end{aligned}$$

TABLE 1b. Calculated Flow Rates for Outfall A					
A	**B**	**C**	**D**	**E**	**F**
Sample Number	**Time (minutes)**	**Total Rainfall Depth (inches)**	**Incremental Time (minutes)**	**Incremental Rainfall (inches)**	**Calculated Flow Rate (cfm)**
1	0	0.0	0	0.0	-
2	20	0.2	20	0.2	84
3	40	0.3	20	0.1	42
4	60	0.5	20	0.2	84
5	80	0.6	20	0.1	42
6	100	0.8	20	0.2	84
7	120	0.9	20	0.1	42
8	140	1.0	20	0.1	42
9	160	1.1	20	0.1	42

Step 7: Plot the flow rate versus time (column F vs. column B).



Step 8: Calculate the total volume geometrically by determining the area under the curve.



$V_1 = V_{\text{Time 0 to Time 20}} = ½ (Q_2 – Q_1)(t_2 – t_1) = ½ (84 – 0)(20 – 0) = 840\ ft^3$
$V_2 = ½ (Q_2 – Q_3)(t_3 – t_2) + Q_3 (t_3 – t_2) = ½ (84 – 42)(40 – 20) + 42 (40 – 20) = 1{,}260\ ft^3$
$V_3 = ½ (Q_4 – Q_3)(t_4 – t_3) + Q_3 (t_4 – t_3) = ½ (84 – 42)(60 – 40) + 42 (60 – 40) = 1{,}260\ ft^3$
$V_4 = V_2 = 1{,}260\ ft^3$
$V_5 = V_3 = 1{,}260\ ft^3$
$V_6 = V_2 = 1{,}260\ ft^3$
$V_7 = Q_7 (t_8 – t_7) = 42 (140 – 120) = 840\ ft^3$
$V_8 = V_7 = 840\ ft^3$
$V_9 = ½ (Q_9 – Q_{10})(t_{10} – t_9) = ½ (42 – 0)(180 – 160) = 420\ ft^3$

$V_t = V_1 + V_2 + V_3 + V_4 + V_5 + V_6 + V_7 + V_8 + V_9 = 9{,}240\ ft^3$
Total Volume = 9,240 cubic feet (262,000 liters)